Fermi National Accelerator Laboratory

FERMILAB-Pub-89/233

High-Pressure Ionization Chambers for Calorimetry in High-Energy Physics*

N. D. Giokaris
The Rockefeller University
New York, NY 10021

D. F. Anderson, S. Cihangir, and B. J. Kross
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, IL 60510

D. Carlsmith
University of Wisconsin
Madison, WI 53706

November 1989

* Submitted to Nucl. Instrum. Methods A

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

FERMILAB-PUB-89/233
November 1989

HIGH-PRESSURE IONIZATION CHAMBERS FOR CALORIMETRY IN HIGH-ENERGY PHYSICS

N.D. Giokaris
The Rockefeller University, New York, NY 10021, USA

D. F. Anderson, S. Cihangir, and B. J. Kross
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

D. Carlsmith
University of Wisconsin, Madison, WI 53706, USA

(Submitted to Nuclear Instruments and Methods A)

The size and speed of signals produced by alpha particles in pure argon gas at pressures up to 160 atm have been studied. At 100 atm the charge collection efficiency is 80% with much of the loss attributable to recombination. With the addition of 1% methane and an electric field of 1 kV/mm the electron collection time is 60 nsec/mm. The signal size and speed at 100 atm is not affected by O_2 for concentrations of up to 80 ppm.

1. Introduction

There is now a great deal of interest in unity gain readout techniques for calorimetry. The most notable ones are liquid argon (LAr)[1] and the warm liquids TMS and TMP[2]. The major advantage of these liquids is that they lend themselves to instruments with good granularity and fine longitudinal segmentation. The major disadvantage of LAr is that it requires a cryostat; 4π detectors using this technique have considerable numbers of cracks, or regions that are blind to passing particles.

As for the warm liquids, TMS is no longer seriously considered for any large experiment because of safety problems, while TMP is receiving consideration by several groups[3]. Like all warm liquids, its main disadvatage is that it is very sensitive to impurities on the ppb level. This has been solved by enclosing the TMP in many sealed boxes. These boxes are very expensive and have a substantial fraction of their area that is insensitive. Also, warm liquids have been shown to have about the same sensitivity to radiation damage as plastic scintillators[4] which is not adequate for high-rate, and therefore high radiation dose, experiments at the Superconducting Super Collider (SSC), Large Hadron Collider (LHC), or in many fixed-target experiments.

An additional problem of LAr and TMP is that the collection time for the electrons is long. At 1.5 kV/mm the collection time for both liquids is about 250 nsec/mm[5]. This, of course, is not a problem for many experiments, but for the SSC and for many of the high-rate fixed-target experiments this is a real concern. Their high capacitance makes fast charge collection even more difficult.

An additional means of readout for calorimetry that is now receiving a great deal of attention is the use of scintillation fibers. This technique solves the problem of the liquids, but does not lend itself to longitudinal segmentation, which is important for particle identification. Also, used with photo multiplier tubes the readout is not unity gain and thus requires constant calibration.

The technique we have been studying is that of high-pressure ionization chambers. A similar work was started by M.Barranco-Luque et al.[6] at CERN in 1981 and after moderate success the project was abandoned[7]. We have studied argon gas at pressures of up to 160 atm and have also added small amounts of methane to increase the drift velocity. The results reported in this work were all obtained with an ^{241}Am alpha source of strength 20 nCi in a planar geometry. Results with a beta source and in a cylindrical geometry will be reported in a future publication.

2. Experimental Setup

In the field of particle detectors, little is known about the operation of gas ionization chambers at high pressures. We therefore designed and built the high-pressure vessel, with a gas volume of about one liter, shown in Fig. 1. The vessel has two high-pressure electronic feed-throughs, one connected to the cathode and the other not in use. The gas was brought into the vessel through piping (not shown in Fig. 1). The vessel was evacuated to normally 10 to 20 millitorr before it was filled up with gas. The argon gas used was Matheson grade with 99.9995% minimum purity.

The ^{241}Am alpha-particle source was implanted on the center of the 2 cm diameter cathode. A positive high voltage was applied to an equal size metallic plate opposite the cathode. The gap between the two plates could be varied from 2 mm to 10 mm. All the measurements reported in this paper were done with a 2.5 mm gap.

The preamp used was a calibrated charge sensitive amplifier (Ortec 142 PC) with a fast response, a 50 μsec decay time and a sensitivity of 6.5 volts/pC. The signal was then shaped by an Ortec 450 amplifier with 1 μsec shaping time and analyzed by a multichannel analyzer.

The electronic readout system was calibrated in the following two ways:

a) A pulser was used to provide a signal at the input of the preamp with a known sensitivity. Measuring simultaneously the preamp output pulse height and pulse spectrum on the multichannel analyzer, the number of channels per pC at the preamp input could be deduced.

b) The multichannel analyzer pulse height spectrum with the alpha source and at relatively low pressures (~15 atm argon) was observed. Because of the large alpha particle range in 15 atm argon and their wide range of angles the spectrum was broad. If we assume the charge collection efficiency at this pressure to be 100%, the maximum of the above spectrum should correspond to the total charge liberated by the alpha particles in the gas. This charge can be calculated from the known alpha particle energy (5.5 MeV) and the energy of 26 eV required to create one ion pair[8].

The calibrations of these two methods differed by only 1%. In this paper we will use the calibration of method a) and we will assign an error of +/- 5%, which represents the reproducibility of the calibration.

3. Experimental Results

The signal as a function of the electric field is shown in Fig. 2 for pure argon at 100 atm and for 100-atm argon with 50 ppm O_2. The error in these measurements, representing their reproducibility, is about +/-2% in addition to the overall calibration error of +/- 5%. The dependence of the signal on the electric field for LAr[9] is also shown for comparison. The alpha-particle signal from 100-atm argon gas saturates faster and is larger by a factor of about 10 than in the LAr case. This is due to high recombination of charge in the LAr. We also observe that 50-ppm O_2 has virtually no effect on the signal size of the 100-atm argon gas for the whole electric field range.

The dependence of the signal size on the pressure is shown in Fig. 3 for pure argon and for argon mixed with 100 ppm O_2. The reduced electric field (E/P) was kept constant at 0.01 $kV^*mm^{-1*}atm^{-1}$ except for the last two pressure points (137 and 163 atm) for which it was 0.0082 and 0.0076 $kV^*mm^{-1*}atm^{-1}$, respectively. We could not raise the high voltage for those points because of breakdown in the feed-throughs. Almost all of the charge liberated in the gas is collected at pressures of up to about 50 atm. At 100 atm, about 80% of the total charge is collected. The signal loss due to the 100-ppm O_2 contamination is very small (about 9%).

The time needed to collect all of the charge at 100-atm argon with 1 kV/mm electric field is about 1 μsec corresponding to an electron collection time of 400 nsec/mm. This is longer than one would like for high rate applications. However, we were able to improve the charge collection time by adding a small amount of methane (CH_4). The

(CH_4) used was Matheson grade with 99.99% minimum purity. The price paid is the loss of some of the signal. The dependence of the signal size and of the speed of the signal on the CH_4 concentration, for a total pressure of 100 atm and an electric field of 1 kV/mm, are shown in Fig. 4 and Fig. 5, respectively. With the addition of 1% CH_4 there is about a 25% signal loss relative to the pure argon case. However, the electron collection time drops to ~60 nsec/mm which is seven times shorter than for pure argon at the same pressure and four times better than for liquid argon or TMP at the same electric field. The addition of 0.5% CH_4 to LAr has been shown to reduce the signal from 1 MeV conversion electrons by about 15%[10]. The loss would be much higher for alpha particles in LAr when CH_4 is added. The electron drift velocity as a function of the reduced electric field in 100-atm argon with 1.3% CH_4 is shown in Fig. 6. These measurements agree with those done at lower pressures[11]. One sees from Fig. 5 and Fig. 6 that the drift velocity is very insensitive to both the CH_4 concentration (for concentrations between 0.5% and 1.5%) and to the electric field (for fields in the range of 0.25 kV/mm to 1.25 kV/mm).

Figure 7 and Fig. 8 plot the collected charge as a function of O_2 concentration for pure argon at 100 atm, and for argon and 1.3% CH_4 mixture at 100 atm, respectively. For O_2 concentrations of up to 80 ppm in pure argon and up to 20 ppm in argon with 1.3% CH_4 there is virtually no loss of signal due to O_2. Liquid argon is sensitive to O_2 at a few ppm level[12] and the warm liquids like TMP and TMS are sensitive to O_2 at ppb level[13]. The error for all relative charge measurements (i.e., Figs. 3, 4, 7, and 8) is about +/-2% and represents the reproducibility of these measurements.

4. Conclusions

We have studied the size and speed of signals produced by an ^{241}Am alpha-particle source in high-pressure argon gas. From these studies we estimate that the signal produced by a minimum ionizing particle in 100 atm of pure argon would be at least 10% of what would be collected in the same thickness of liquid argon. The electron collection time at 100 atm argon and electric field of 1 kV/mm is ~400 nsec/mm. Adding ~1% CH_4 in 100 atm of argon reduces the collection time by a factor of about 7 to 60 nsec/mm. This is a factor of 4 shorter than for LAr or TMP. Furthermore, our calculations show that in a calorimeter with a sampling medium of argon gas at 100 atm plus ~1% CH_4 and lead absorber, there is enough primary ionization charge produced so that particle energies down to 100 MeV to 200 MeV could be easily measured. [1] Since such a calorimeter could be extremely radiation hard (the effect of radiation on low concentrations of CH_4 has to be tested) we believe that it could be an attractive alternative to existing technologies for high-luminosity colliders (e.g., SSC, LHC) es-

[1] To do this calculation, a sampling medium to absorber volume ratio of 1:3 was assumed. The electron to muon and the electron to pion ratios were taken to be 1.5 and 1.15, respectively. The maximum source capacitance was assumed to be 1 nF and the noise level for a standard calorimeter preamp was taken to be 1 fC, or 6000 electrons per 1 nF of source capacitance.

pecially at the very forward regions where the radiation levels will be very high. This technique has unity gain, does not require a cryostat as does LAr, is less sensitive to impurities by several orders of magnitude than warm liquids, and also solves the problems of neutron-induced pulses ("Texas Towers")[14] and glow mode (localized and self sustained discharge) encountered at high rates in calorimeters using 1 atm gas as a sampling medium. High-pressure ionization chambers can also lead to construction of calorimeters with fine transverse and longitudinal segmentation. Another application of these technique could be as position detectors in the electromagnetic shower maximum. There is, of course, a significant R&D effort needed to solve the mechanical problems associated with the high pressure, and to develop practical and cost-effective calorimeter designs.

References

[1] W. J. Willis and V. Radeka, Nucl. Instr. and Methods 120 (1974) 221;
W. Hofmann et. al., Nucl. Instr. and Methods 135 (1976) 151;
F. Lobkowicz et. al., Nucl. Instr. and Methods A235 (1985) 332;
M. David, Nucl. Instr. and Methods A265 (1988) 319.

[2] A. Gonidec et. al., Ionization Chambers with Room-Temperature Liquids for Calorimetry, CERN-EP/88-36, 23 March 1988.

[3] M. G. Albrow et. al., Nucl. Instr. and Methods A265 (1988) 303.

[4] R. A. Holroyd, Effects of Radiation Damage to Ionization Chamber Liquids, to be published in IEEE Trans. Nucl. Sci. NS-37 (1990).

[5] R. A. Holroyd and D. F. Anderson, Nucl. Instr. and Meth. A236 (1985) 294.

[6] M. Barranco-Luque et al., BNL31100, OG 624.

[7] T. Ludlam, Private Communication.

[8] F. Sauli, Principles of Operation of Multiwire Proportional and Drift Chambers, CERN 77-09, 3 May 1977.

[9] D.F. Anderson, Nucl. Instr. and Methods A245 (1986) 361.

[10] E. Shibamura et al., Nucl. Instr. and Methods 131 (1975) 249.

[11] I. Lehraus, IEEE Trans. Nucl. Sci. NS-30 (1983) 50.

[12] S. D. Biller et. al., Nucl. Instr. and Methods A276 (1989) 144.

[13] S. Oxhsenbein et. al., Nucl. Instr. and Methods A273 (1988) 654.

[14] S. Cihangir et al., IEEE Trans. Nucl. Sci. NS-36, No. 1 (1989) 347.

Figure Captions

Figure 1) High-pressure vessel and readout electronics.

Figure 2) Collected charge as a function of electric field for 100-atm argon, 100-atm argon with 50-ppm oxygen gas mixture and liquid argon.

Figure 3) Collected charge as a function of pressure in argon and in argon plus 100-ppm oxygen mixture. The ordinate scale is normalized to the total charge liberated by 5.5 MeV alpha particles in pure argon gas. The solid line is drawn to guide the eye.

Figure 4) Collected charge as a function of methane concentration in 100-atm argon gas. The ordinate scale is normalized to the total charge liberated by 5.5 MeV alpha particles in 100-atm pure argon gas and at an electric field of 1kV/mm.

Figure 5) Electron collection time as a function of methane concentration in 100-atm argon gas.

Figure 6) Drift velocity of electrons as a function of the reduced electric field(E/P) in 100-atm argon plus 1.3% methane gas mixture.

Figure 7) Collected charge as a function of oxygen concentration in 100-atm argon gas. The ordinate scale is normalized to the total charge liberated by 5.5 MeV alpha particles in pure argon gas at the same pressure and electric field.

Figure 8) Collected charge as a function of oxygen concentration in 100-atm argon and 1.3% methane gas mixture. The ordinate scale is normalized to the total charge liberated by 5.5 MeV alpha particles in pure argon gas at the same pressure and the same electric field.

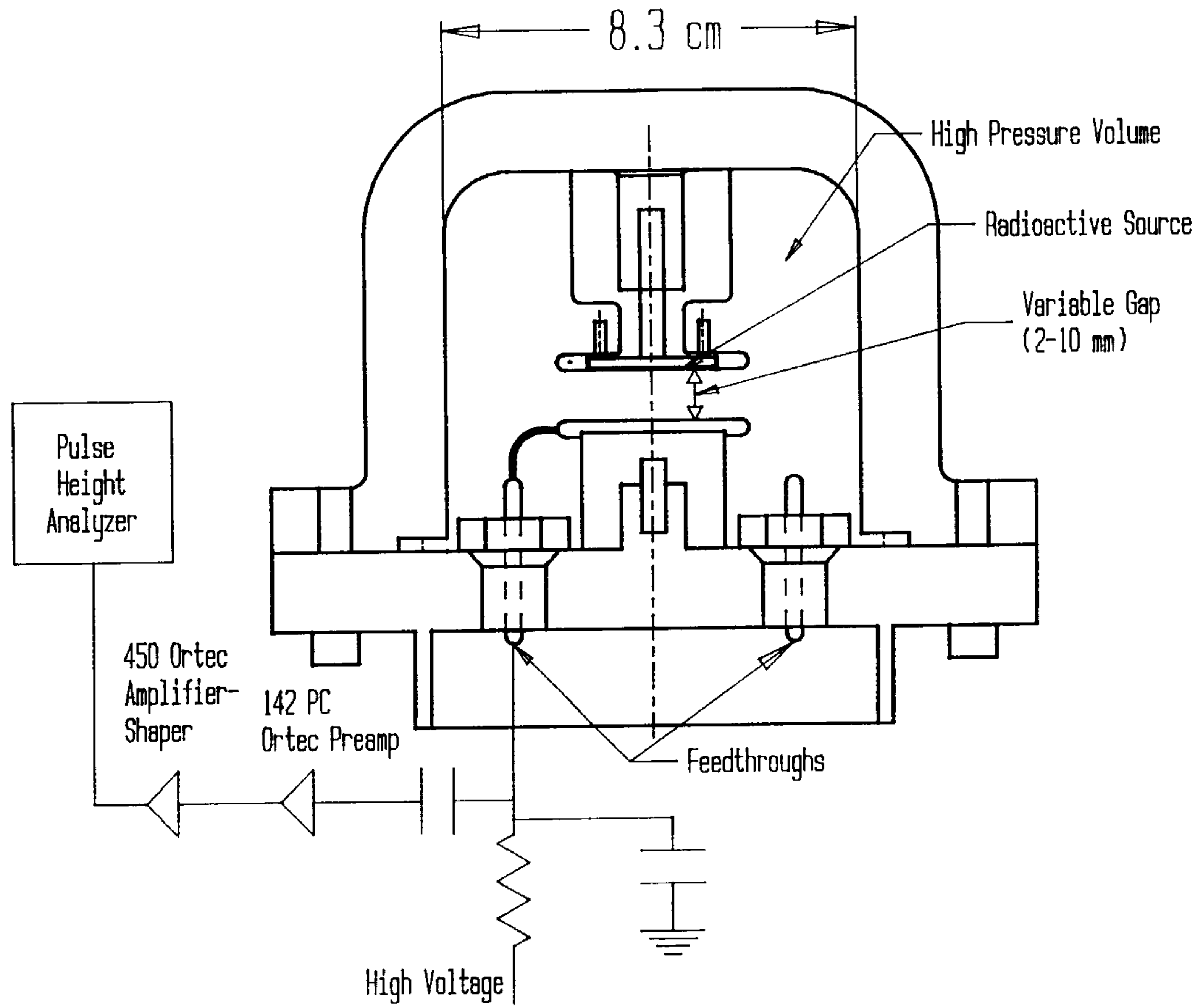
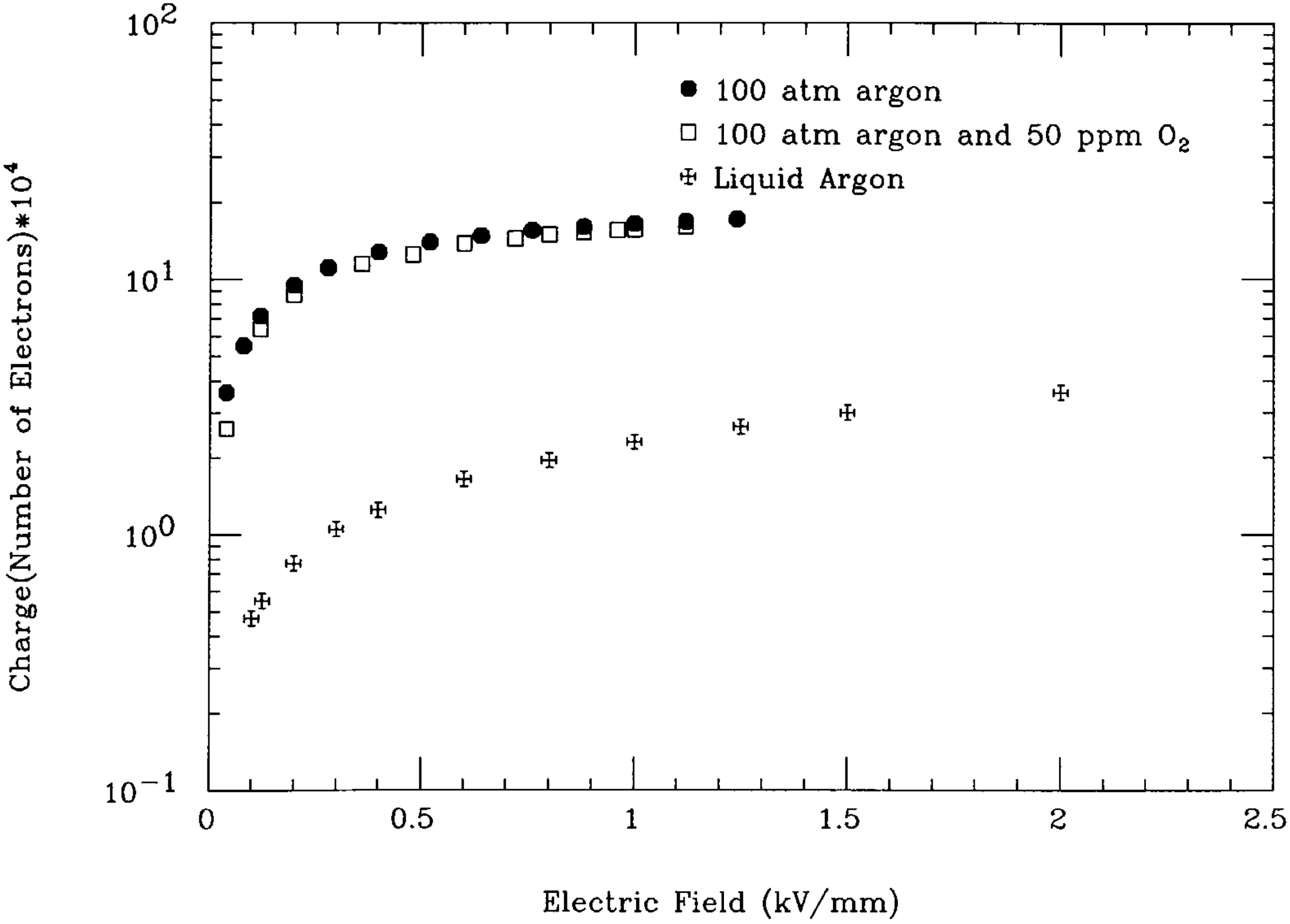
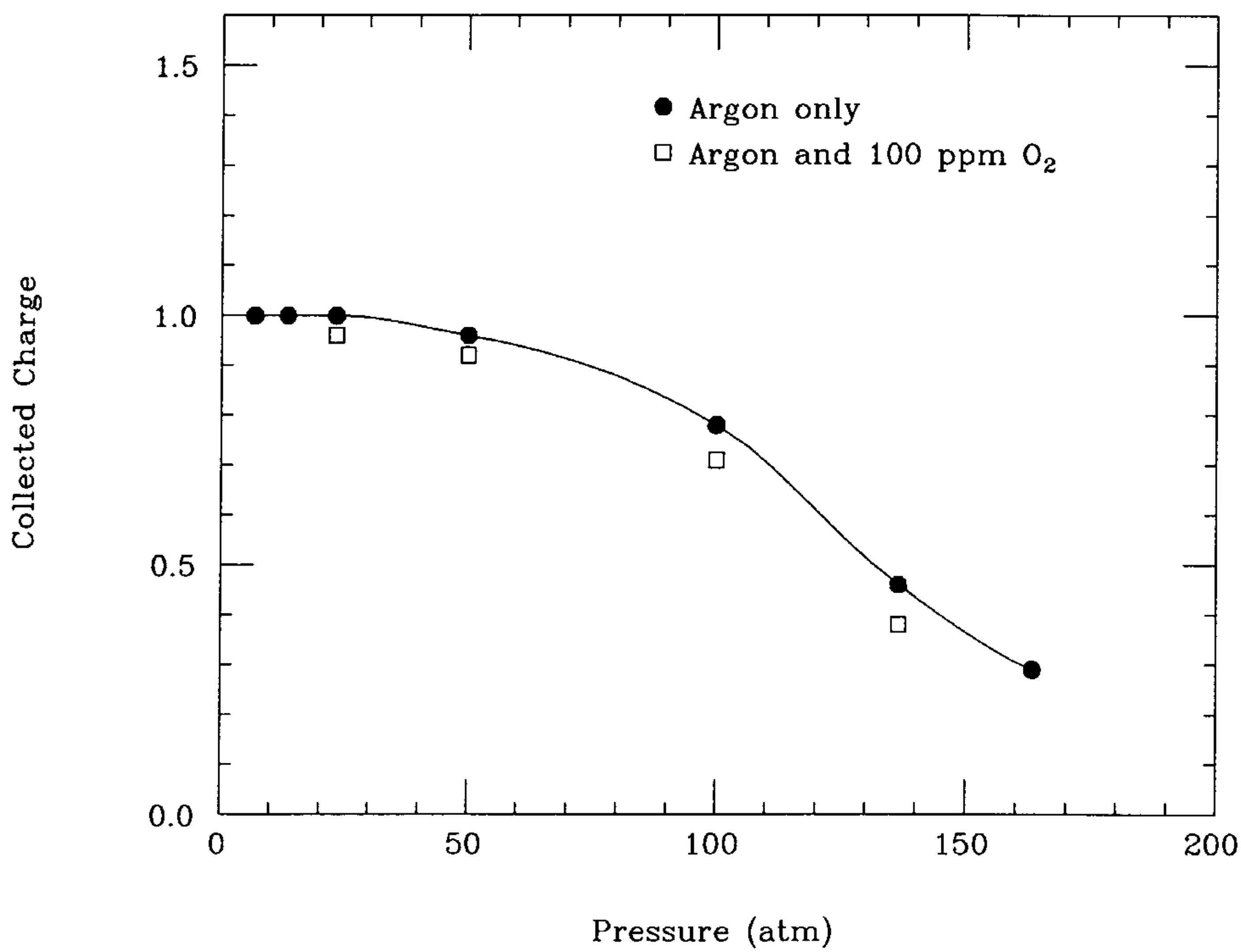

8.3 cm
High Pressure Volume
Radioactive Source
Variable Gap
(2-10 mm)
Pulse
Height
Analyzer
450 Ortec
Amplifier-
Shaper
142 PC
Ortec Preamp
Feedthroughs
High Voltage

Figure 1



100 atm argon
100 atm argon and 50 ppm O_2
Liquid Argon
Charge(Number of Electrons)*10^4
10^2
10^1
10^0
10^{-1}
0
0.5
1
1.5
2
2.5
Electric Field (kV/mm)

Figure 2



Argon only
Argon and 100 ppm O_2
Collected Charge
0.0
0.5
1.0
1.5
0
50
100
150
200
Pressure (atm)

Figure 3

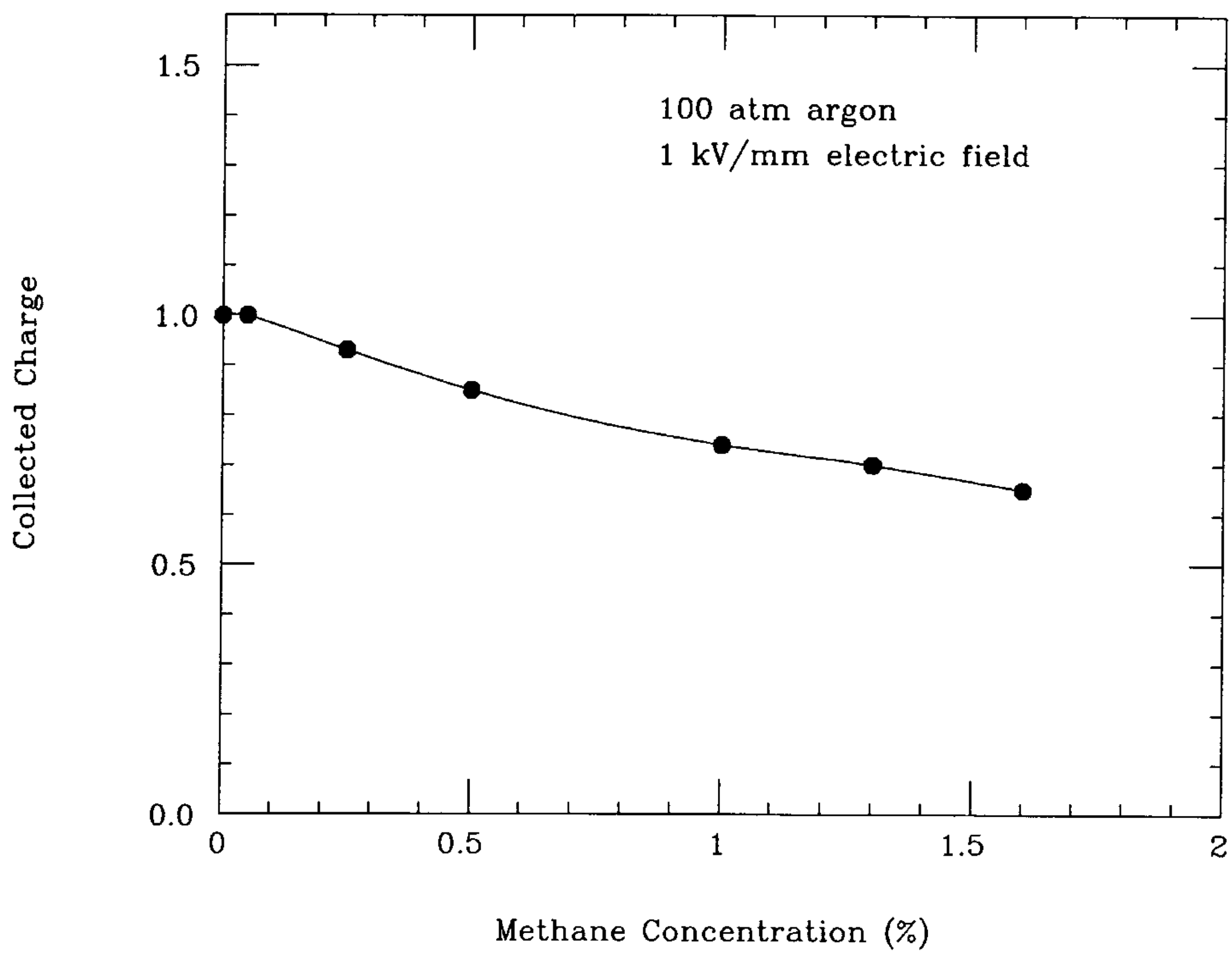

100 atm argon
1 kV/mm electric field
Collected Charge
1.5
1.0
0.5
0.0
0
0.5
1
1.5
2
Methane Concentration (%)

Figure 4

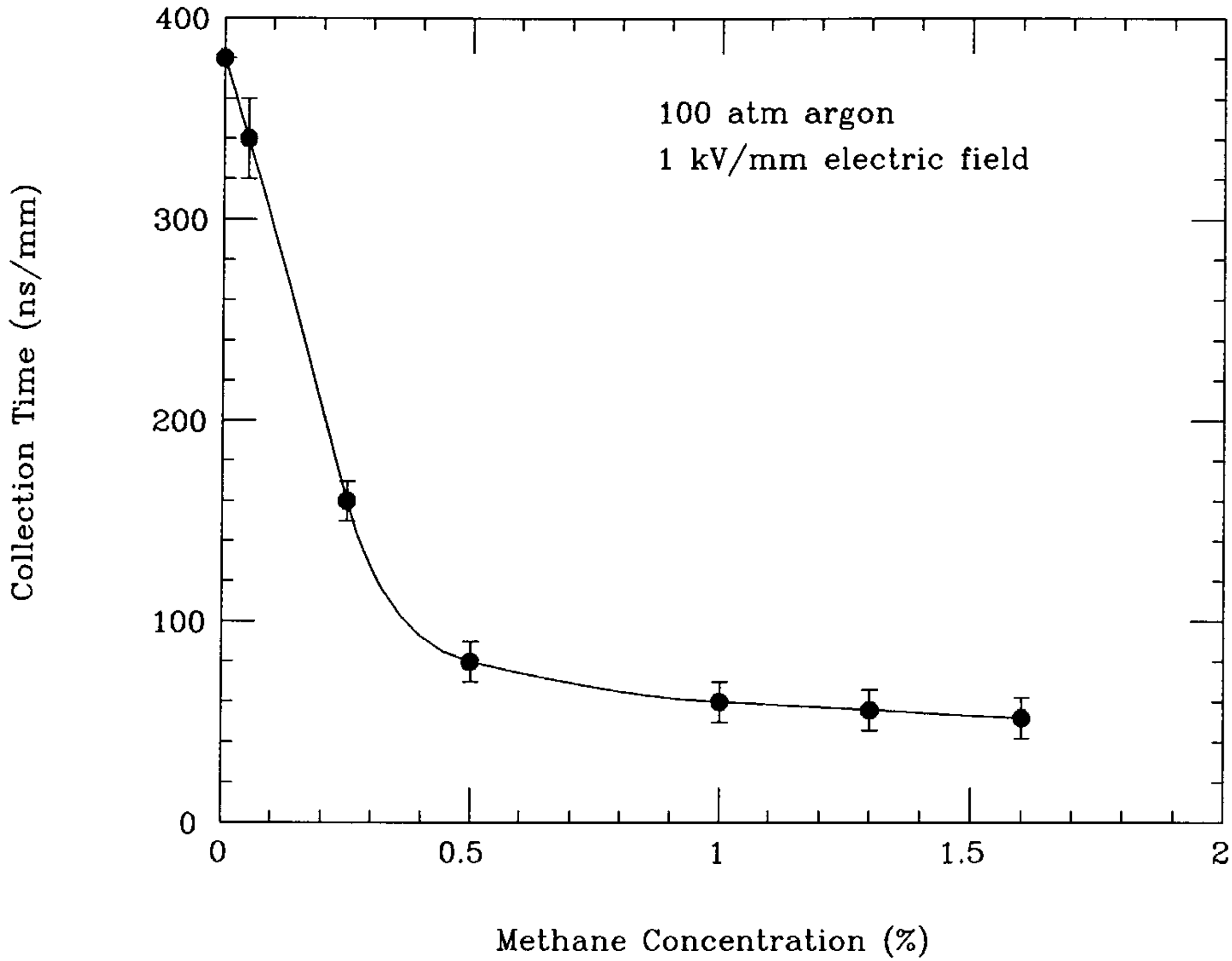

400
300
200
100
0
Collection Time (ns/mm)
100 atm argon
1 kV/mm electric field
0
0.5
1
1.5
2
Methane Concentration (%)

Figure 5

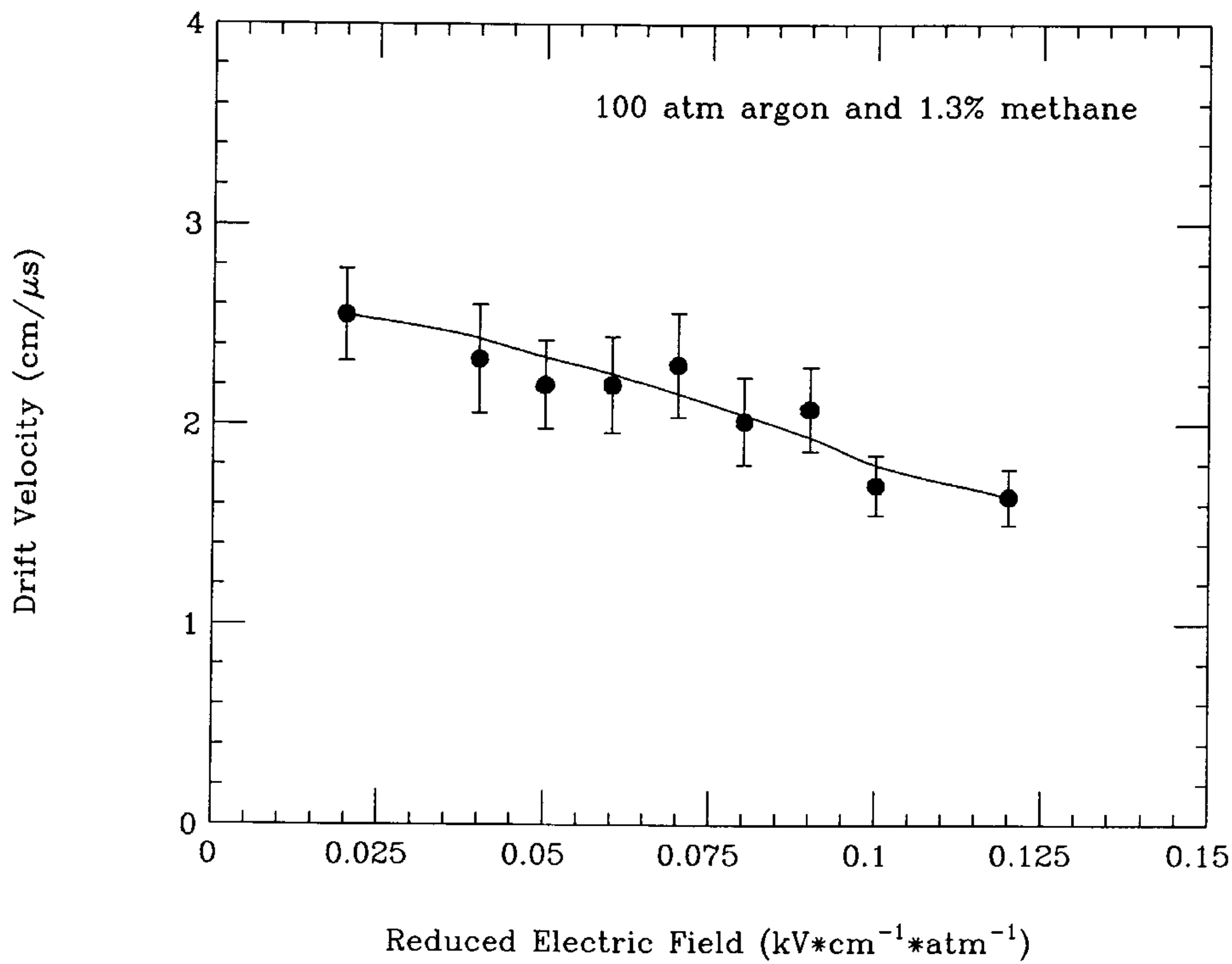
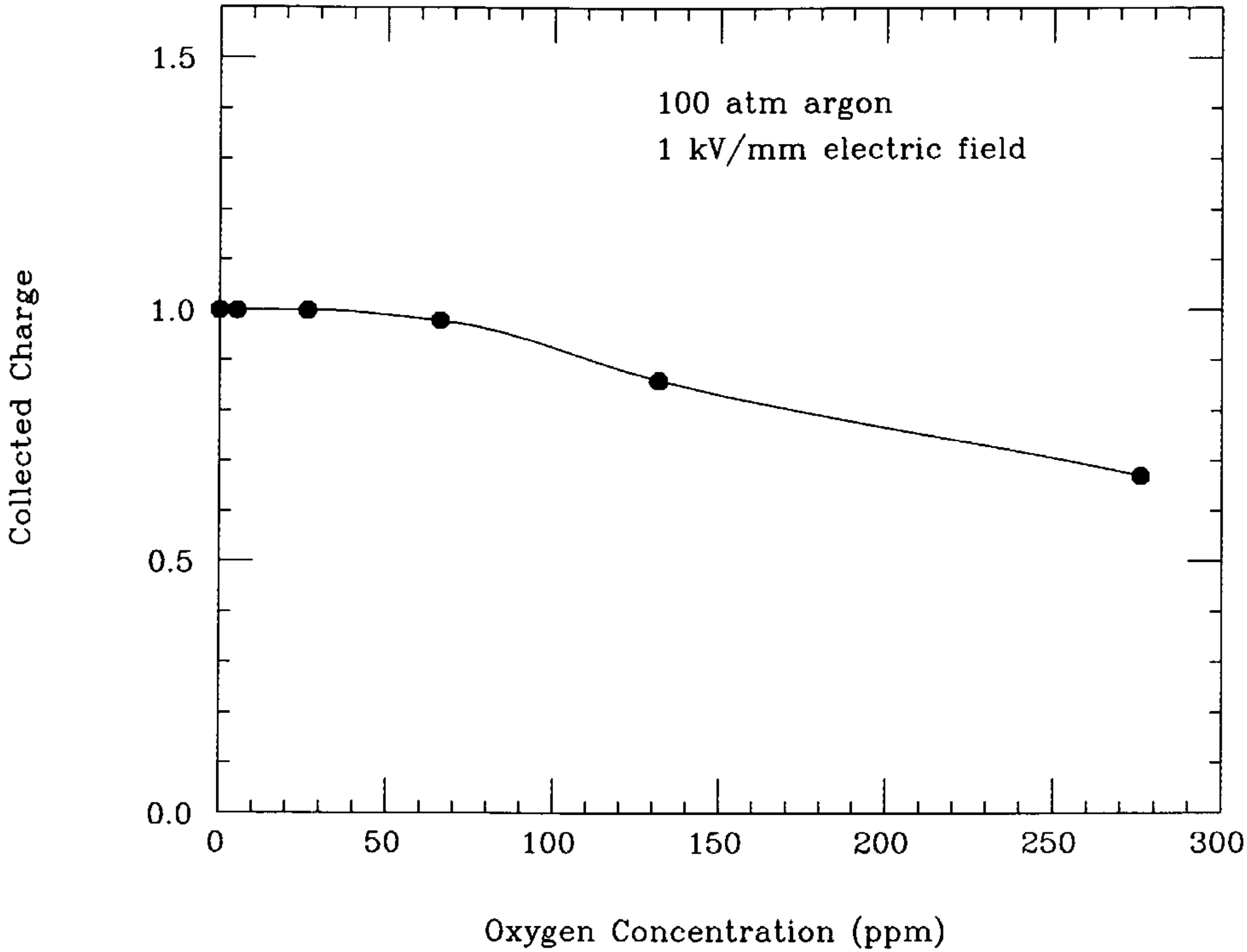

100 atm argon and 1.3% methane
Drift Velocity (cm/μs)
Reduced Electric Field (kV*cm⁻¹*atm⁻¹)
0
1
2
3
4
0.025
0.05
0.075
0.1
0.125
0.15

Figure 6



100 atm argon
1 kV/mm electric field
Collected Charge
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Oxygen Concentration (ppm)

Figure 7

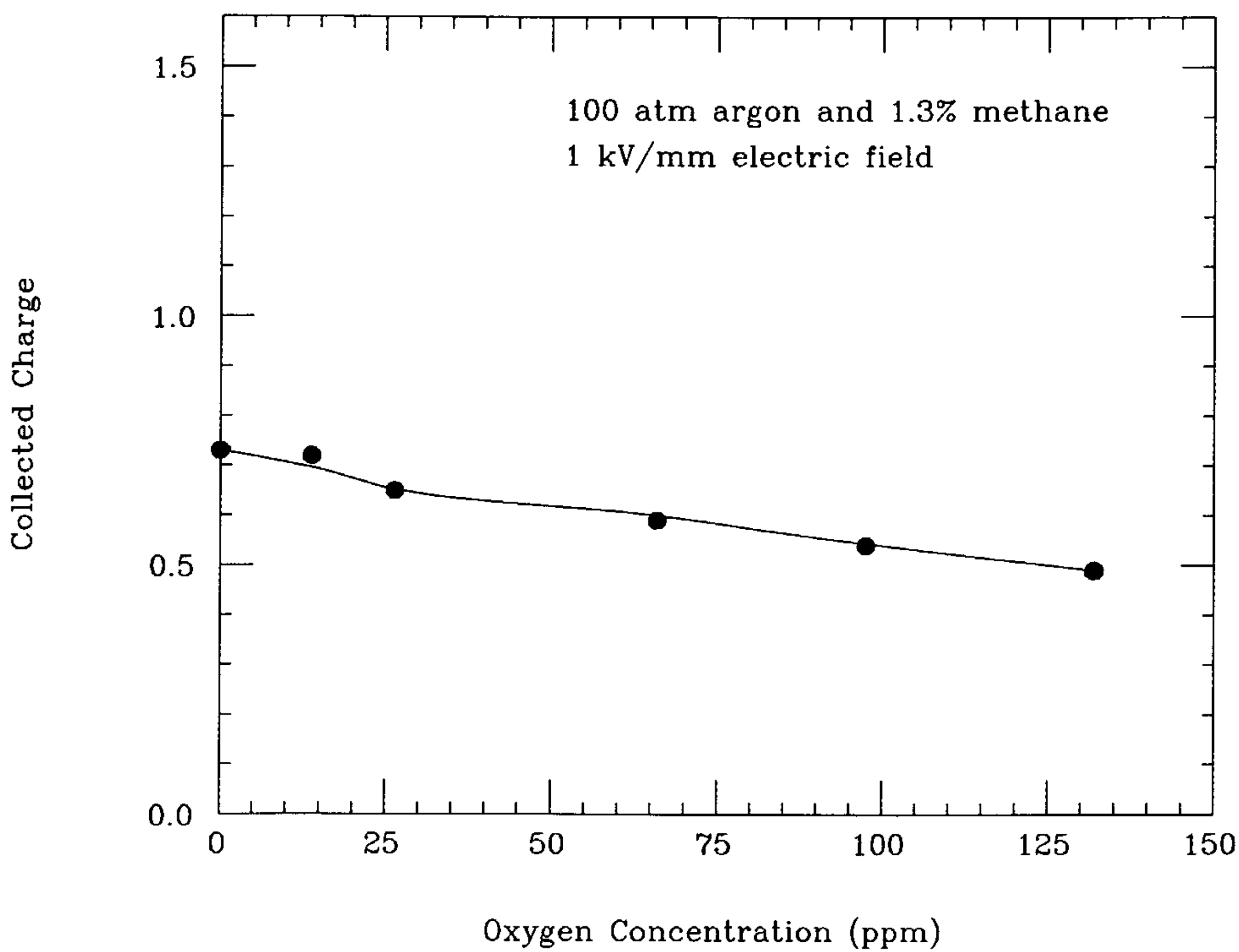

100 atm argon and 1.3% methane
1 kV/mm electric field
Collected Charge
1.5
1.0
0.5
0.0
0
25
50
75
100
125
150
Oxygen Concentration (ppm)

Figure 8